

Decline of demersal resources in North-West Africa: an analysis of Mauritanian trawl-survey data over the past 25 years

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Mauritania is characterised by fast-growing fisheries that have developed over the past decades. Since 1982, scientific trawl surveys have been conducted regularly, allowing assessment of the impact of this increasing fishing pressure on exploited species as well as on demersal communities. Based on 55 bottom trawl surveys and using linear model techniques, the annual abundances were estimated for a selection of 24 fish stocks and for the whole demersal biomass. Changes in the demersal community structure were also investigated, using Biomass Trophic Spectra representations. It is shown that the demersal biomass has been reduced by 75%

on the Mauritanian continental shelf over the past 25 years, corresponding to a biomass loss of around 20 000t per year. Top predators abundance has been reduced by 8–10-fold and in some case up to 20-fold. The trophic structure has been significantly modified and the mean trophic level of the catchable biomass decreased from >3.7 to <3.5. The results are discussed at the regional scale, taking into account recent studies in Senegal and Guinea in which a similar decline in demersal biomass was observed. This decline was due to severe overexploitation that affected the various groups in succession.

Keywords: biomass decrease, demersal resources, Mauritania, North-West Africa, trawl survey, trophic structure

Introduction

The worldwide decline in marine resources as a result of overexploitation is now well known, not only to fisheries scientists but also to decision-makers and the general public. This decline has been documented mostly on a large-scale basis, using mainly commercial catch statistics. This was the case, for instance, in the benchmark works of Myers and Worm (2003), who showed a worldwide decline in abundance of large predatory fish, and Worm *et al.* (2006) who predicted that all fish stocks worldwide would be overexploited by 2048. Similarly, significant changes in the trophic structure of fish communities have been shown using data based on commercial catches; most notably the provocative work of Pauly *et al.* (1998) that demonstrated the 'fishing down marine food web' process.

Such approaches have been very controversial (Ben Yami 2003, Hampton *et al.* 2005, Sibert *et al.* 2006), particularly because commercial catch data could be biased by changes in fishing technology or strategies. Certainly, analyses based on scientific surveys should provide more reliable data, and specific cases studies remain crucial in order to characterise and quantify trends in marine exploited resources at various scales, from stock to community levels. However, available survey data-series are often too short to cover the period of the expansion of specific fisheries.

From that perspective, the north-western part of the African continental shelf is one of the better areas worldwide to analyse the impact of fisheries on demersal resources. The region is characterised by fast-growing fisheries that have developed over the past several decades from low levels of fishing to intense fishing and have led to severe decreases in biomass and serious signs of overexploitation (Christensen *et al.* 2004, Gascuel *et al.* 2004). Starting relatively early in the course of the fisheries development process, important research programmes that incorporated scientific trawl surveys have been conducted, thus allowing evaluation of the impact of fishing on exploited species, including demersal communities.

Most of these surveys have been conducted on a national basis. In Mauritania, Senegal and Guinea, research surveys were initially carried out with the support of the French Institut de Recherche pour le Développement (IRD) and more recently by the national fisheries research institutes themselves. In Senegal and Guinea, survey data have been intensively analysed, particularly during the recent European project Fisheries Information and Analysis System (FIAS). Results from this source have shown a decrease in the biomass of exploited demersal species and significant changes in the trophic structures of

demersal communities (Laurans *et al.* 2004a). However, in Mauritania, only cursory analyses of the data from trawl surveys have been undertaken to examine the trends of abundance of demersal communities, leading to very preliminary results (Failler *et al.* 2006).

The aim of this present paper is to generate a first representation of the trends observed in Mauritanian demersal resources over the past 25 years. Based on information from the trawl survey database of the Institut Mauritanien de Recherches Océanographiques et des Pêches (IMROP), two complementary approaches were considered. Firstly, applying linear models, annual abundances for a selection of 24 demersal stocks and for the whole catchable biomass were estimated. Secondly, changes in the demersal community structure were investigated using Biomass Trophic Spectra as an ecosystem indicator (Gascuel *et al.* 2005). Results are discussed at the regional scale, in the context of previous studies undertaken in Senegal and Guinea.

Material and Methods

Trawl surveys selection and preliminary data processing

Although more than 100 experimental bottom trawl surveys have been carried out since 1982 on the Mauritanian continental shelf, they were not all conducted for the same purposes so sampling protocols or fishing techniques varied greatly. In the present analysis, only standard surveys that sampled the demersal resources over the whole Mauritanian continental shelf were considered. In these surveys, sampling stations were randomly chosen by geographic area, each area being defined by a range of latitude and depth (Figure 1). The surveys normally covered all the continental shelf from the coast to the 200m isobath, and the occasional deeper hauls have been excluded from the analysis. The bottom trawl used was an 'Irish-type trawl' with a 40mm mesh size and a 17m-wide opening, towed at 3.5 knots for 30min. In all, 55 surveys, totalling 4 339 trawls, were selected from the IMROP database. Both the cool and the warm seasons were sampled.

The survey vessel used until 1996, the *N'Diogo*, was replaced in 1997 by the *Al Awam*. However, no cross-calibration studies were conducted at the time of this change. Nevertheless, the same trawl was used and similar protocols were maintained to maintain a constant fishing power. As proposed by the scientists involved in these surveys, we have assumed here that the observations from both vessels constituted a continuous and homogeneous dataset.

Furthermore, the fishing gear was modified in early 1989. Old wooden trawl panels were replaced by metallic 'Morgère' panels and the trawl footropes were reinforced. This change effectively increased the trawl fishing power, and two cross-calibration surveys conducted in 1989 and 1990 showed that the fishing efficiency had indeed been improved by this change (Girardin *et al.* 1990). Standardisation coefficients by species groups have been estimated for both gears, based on published data (Gascuel *et al.* in press b, Table 1).

Of the 483 different taxa identified from the 55 surveys under study, 375 were considered in the present study, representing over 99.5% of the total catches over the whole period.

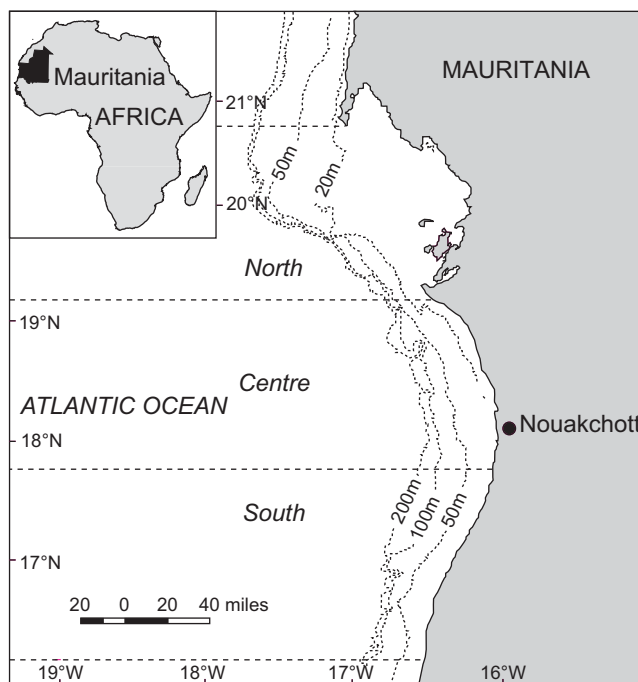


Figure 1: Map of Mauritania showing the continental shelf and strata boundaries

All catches from the surveys conducted before 1988 (inclusively) were multiplied by the corresponding standardisation coefficient according to Table 1.

For many taxa, including abundant but heterogeneously distributed species, catches were zero in a large majority of the hauls. Therefore, aggregated observations were considered rather than the individual catch per haul. Zero catches were mainly on account of the small size of the surveyed surface per haul, which constituted an insufficient observation unit. Therefore, catches from each survey were aggregated per stratum, each stratum being defined by a range of latitude and depth. These total catches were divided by the trawled area and were expressed in term of density ($t\ km^{-2}$). The trawled area is a function of the number of hauls and the surface area trawled (S_h) per haul:

$$S_h = 3.5\ \text{knots} \times 1\ 852\ \text{m}\ h^{-1} \times 17\ \text{m} \times 0.5\ \text{h} \times 10^{-6} = 0.055\ \text{km}^2$$

Biomass estimates

The biomass of 24 different demersal taxa, selected for their importance in the survey catches and/or in the fishery, was estimated for each year over the whole continental shelf. Additionally, two 'total biomasses' were estimated; one that combined all species caught during the surveys and the other that did not include pelagic species, which were obviously not sampled efficiently using a bottom trawl. Estimates were based on linear model techniques, using a standard model expressed as follows:

$$D_{y,s,l,r} = I A_y \times d_{s,l,r} \times \varepsilon$$

where:

Table 1: Standardisation coefficient between trawls before and after 1989. Pg expressed for each group as the ratio of fishing efficiency after/before this change (in Gascuel *et al.* in press b; based on the data of Girardin *et al.* 1990)

Group	Taxon	Pg
Octopus	<i>Octopus</i> sp.	3.01
Benthic fish	Pleuronectiformes, rays (Batoidae), Scorpaenidae, Triglidae, Uranoscopidae	8.64
Crustacean	Decapods natancia, Decapods reptancia	2.49
Demersal fish	Sparidae, Serranidae, Pomadasyidae, and all other families not included in 'benthic fish'	2.14
Other cephalopods	Sepiidae, Sepiolidae, Lolidinae, Ommastrephidae	2.22
Pelagic fish	Clupeidae, Engraulidae, Carangidae, Stromateidae, Scombridae, Sphyrinae, Pomatomidae	1.46

Table 2: Depth and latitudinal boundaries and surface areas of the strata used in the present study (modified from IMROP 2004)

Depth	Area (km ²)		
	North (19°15'–20°36'N)	Centre (17°39'–19°15'N)	South (16°04'–17°39'N)
5–20m	10 653	2 783	1 485
20–50m	2 460	1 983	1 861
50–80m	1 754	1 722	1 584
80–200m	1 147	2 767	3 025

$D_{y,s,l,r}$ is the density (in t km⁻²) observed during year y and season s, in the stratum corresponding to the latitude class l and the depth range r;

IA_y is an index of global stock abundance (in t km⁻²) for year y;

$d_{s,l,r}$ is a scaling factor or index of relative abundance by stratum for each season; and

ε is the error term whose distribution is assumed lognormal.

Initially, the model took into account two seasons (the cool season from December to June, and warm season from July to November) and 12 spatial strata combining depth and areas (Table 2). Using this model, we estimated for each taxon an average bathymetric distribution for the whole study period. It was assumed that this distribution was constant over years. However, we considered that it may vary between latitudinal areas and seasons, but we also tested more parsimonious models that ignored either the seasonal or the area effect, or their interaction with depth. The $d_{s,l,r}$ term expresses the species-specific general distribution pattern.

Models were fitted using R software (Ihaka and Gentleman 1996). For each taxon, the biomass estimates were derived from the predicted values of densities as follows:

$$B_y = \frac{1}{2} \times \sum_{s,l,r} (IA_y \times d_{s,l,r} \times S_{l,r})/q$$

where:

B_y is an average biomass (t) for the year (average of both seasons);

$S_{l,r}$ is the surface area for latitudinal class l and depth range r (see Table 2); and

q is a catchability coefficient expressing the fact that not all animals present in the trawled area were caught. Conventionally, we used a value $q = 0.5$ for all fish studied, $q = 0.2$ for octopus and sepioid, and $q = 0.4$ for the total catchable biomass. These values are discussed later.

In addition, statistical interactions between year and spatial effects were tested to detect distribution changes that could

have occurred during the study period, which could bias abundance estimates. When such cross-effects were found to be significant, biomasses were estimated by year and by depth or latitudinal class. The total biomass was estimated as the sum of biomasses by stratum.

Trends in biomass estimates were tested by calculating the linear coefficient of correlation between biomass and year. When the trend appeared significant, an average yearly rate of biomass decrease was calculated.

Trophic spectra estimate

Average Biomass Trophic Spectra (BTS) were estimated, by five-year increments, for the whole Mauritanian continental shelf. The BTS expresses the distribution of the biomass across trophic levels. This representation is a useful way to synthesise changes in trophic structure at the community level and to detect changes in abundance that may occur within the community (Gascuel *et al.* 2005).

First, a mean trophic level (TL) was determined for each of the 375 taxa. When available, we used the TL value estimated for Senegal and Guinea by Laurans *et al.* (2004a). These values were based mainly on estimates reported in FishBase (Froese and Pauly 2000), but they also took into account results of Ecopath models developed in the region during the FIAS project. For fish species not included on that list, the TL value provided in FishBase was used. When no TL estimate was available (81 taxa, representing <5% of the total biomass), one of the following were used: (1) for fish species, the value of a closely related species (same genus); (2) for fish taxa defined only at the genus or family levels, the average TL of known species of that taxonomic group present in surveys; or (3) for other taxa, the value of the corresponding Ecopath group estimated in the Mauritanian model (Taleb Sidi and Guénette 2004). The trophic level of the broad categories 'other teleosts', 'other rays' and 'other sharks' for the first three years of the survey period (1982–1984) were assumed to be 3.5, 3.9 and 4.1 respectively.

Catches for the selected 375 taxa were aggregated for each survey by stratum and by trophic class of 0.1 increments. These densities by trophic class and strata ($t \text{ km}^{-2}$) constitute the observed data from which we estimated the average biomass by trophic level and year, and the trophic spectra by period using a standard linear model:

$$D_{i,y,s,l,r} = T_{i,p} \times d_{s,l,r} \times \varepsilon$$

where:

$D_{i,y,s,l,r}$ is the density of the trophic class i observed during year y and season s , in the stratum corresponding to the latitude class l and the depth range r ;

$T_{i,p}$ is an index of total abundance of the trophic class i during the five-year period p ;

$d_{s,l,r}$ is an index of spatial distribution by latitude and depth, for each season; and

ε is the error term assumed to follow a lognormal distribution.

Such a model assumes an average (and constant over periods) spatial distribution of the whole demersal biomass, although interactions and alternative models were also tested (see Results).

As done at the stock level, biomass per trophic class and time period was derived from predicted densities multiplied by the strata surfaces. For each period, these biomasses were plotted against trophic level. The plots were then smoothed, using a weighted moving average (Gascuel *et al.* 2005) to account for the inter-individual variability that

characterises the trophic level of each species. The smoothed curves constitute the trophic spectra.

Results

Fit of linear models

The density of all 24 taxa showed significant differences among years and spatial-seasonal strata. In the majority (17 from 24 taxa), the spatio-seasonal strata used in the linear model should be defined as the combination of the three parameters depth, area and season, including their interactions (Table 3). This indicates that the distribution by depth class varies significantly between areas and seasons. For some species, there was no seasonal (4 taxa) or no area (2 taxa) effects, and no interaction between season and area was found for *Ephinephelus aeneus*. In all cases, the standard model is thus based on the most parsimonious spatio-seasonal scheme, assuming it has been constant over the whole sampling period. In all cases except for *Argyrosomus regius*, the model explains more than 50% and up to 90% of the observed variability. This value increases to 98% if total catches are considered.

For some taxa, there were significant interactions between year and depth (10 taxa) or area (4 taxa), indicating changes in the spatial distribution. Inertia related to these interactions were generally low (<10%) and the variance did not change much whether or not the models took the interactions into

Table 3: Statistical results of model fitting: species or category name, coastal (C) or offshore (O), spatial strata retained and coefficient of determination for model without or with interaction between year, and spatial factor

Species	Standard model			Model with interaction			
	C/O	Spatial strata	r^2 adj.	Spatial strata	Interaction effect	r^2 adj.	Interaction inertia (%)
<i>Citharus linguatula</i>	O	Depth:area:season	0.770	Area	Year:depth	0.875	9.1
<i>Dentex angolensis</i>	O	Depth:area:season	0.731	Season	Year:depth	0.805	8.6
<i>Dentex macrophthalmus</i>	O	Depth:area:season	0.661	Area:season	Year:depth	0.732	8.1
<i>Merluccius</i> sp.	O	Depth:area:season	0.740	Area:season	Year:depth	0.745	5.9
<i>Zeus faber</i>	O	Depth:area:season	0.811				
<i>Umbrina canariensis</i>	O	Depth:area:season	0.583				
<i>Raja straeleni</i>	O	Depth:area:season	0.519	Depth:season	Year:area	0.529	7.8
<i>Raja miraletus</i>	CO	Depth:area:season	0.847				
<i>Pagellus bellottii</i>	C	Depth:area:season	0.858	Area	Year:depth	0.837	3.0
<i>Argyrosomus regius</i>	C	Depth:area:season	0.406	Depth:season	Year:zone	0.430	9.4
<i>Pseudupeneus prayensis</i>	C	Depth:area:season	0.757	Area:season	Year:depth	0.734	5.6
<i>Pagrus caeruleostictus</i>	C	Depth:area	0.726	Area	Year:depth	0.738	4.9
<i>Pomadasys incisus</i>	C	Depth:season	0.748	Season	Year:depth	0.757	4.8
<i>Brachydeuterus auritus</i>	C	Depth:area:season	0.674				
<i>Diplodus bellottii</i>	C	Depth:area	0.717				
<i>Cynoglossus</i> sp.	C	Depth:area	0.579				
<i>Dentex canariensis</i>	C	Depth:area:season	0.642				
<i>Arius heudelotii</i>	C	Depth:area:season	0.563				
<i>Pseudolithus senegalensis</i>	C	Depth:area	0.563				
<i>Epinephelus aeneus</i>	C	Depth+area+season	0.698	Area+season	Year:depth	0.732	10.0
<i>Plectorhinchus mediterraneus</i>	C	Depth:area+season	0.650				
<i>Mustelus mustelus</i>	C	Depth:area:season	0.601	Area:season	Year:depth	0.548	6.7
<i>Sepia officinalis</i>	C	Depth:season	0.819	Depth:season	Year:area	0.830	2.7
<i>Octopus vulgaris</i>	O	Depth:area:season	0.906	Depth	Year:area	0.904	2.0
Total		Depth:season	0.982				
Total without pelagics		Depth:season	0.979				
Biomass Trophic Spectra		Depth:area:season	0.791	Area	Period:depth	0.833	4.8

account (Table 3). Nevertheless, models with interaction will be further considered as alternative solutions to analyse biomass trends.

The linear models used to estimate the BTS show a significant interaction ($p < 0.001$) between trophic levels and periods, indicating that both the overall abundance and the trophic structure were modified over time. As in the analyses of catches per taxa, two models were fitted to observed catches by trophic level. The first model assumes that the BTS presents the same shape in all strata and explains 79% of the total variance, and the second one takes into account significant differences in trophic spectra shapes between depth classes and explains a 83% of the total variance.

Trends in species biomass

Individual and cumulative abundances of the 24 taxa under study show year-to-year fluctuations that could be associated with changes in catchability and/or to sampling design variability (Figure 2a). Although interannual fluctuations are important, there is a clear trend showing a marked decrease in abundance over the study period. The cumulative

biomass of the 24 taxa has decreased from just over 200 000t in 1982 to around 60 000t in 2006. Over the same period, the total demersal biomass derived from total survey catches and those excluding pelagic species decreased from around 600 000t to 150 000t (Figure 2b), a fourfold decrease. The average loss per year was 5.8%, or 19 000t. In both the cumulative and total abundance series, the lowest values over the whole time-series were in the last three years (2004–2006). During the period 1989–2006, when the new bottom trawl was used, the decrease was 5.7% per year, indicating that the change in gear did not modify the results.

Based on the standard model, 15 of the 24 taxa showed a significant decreasing trend since 1982 (Figure 3). Only one species (*Diplodus bellottii*) increased in abundance, although at a relatively slow rate (2.2% per year), and this trend did not hold for the period 1989–2006. Abundance decreases in some species were quite marked, with both *Raja* species, as well as *Dentex angolensis* and *Cilharus linguatula*, showing annual declines of close to 10% or more. The estimated biomass decreased from around 70 000t to 15 000t for important species such as *Octopus*

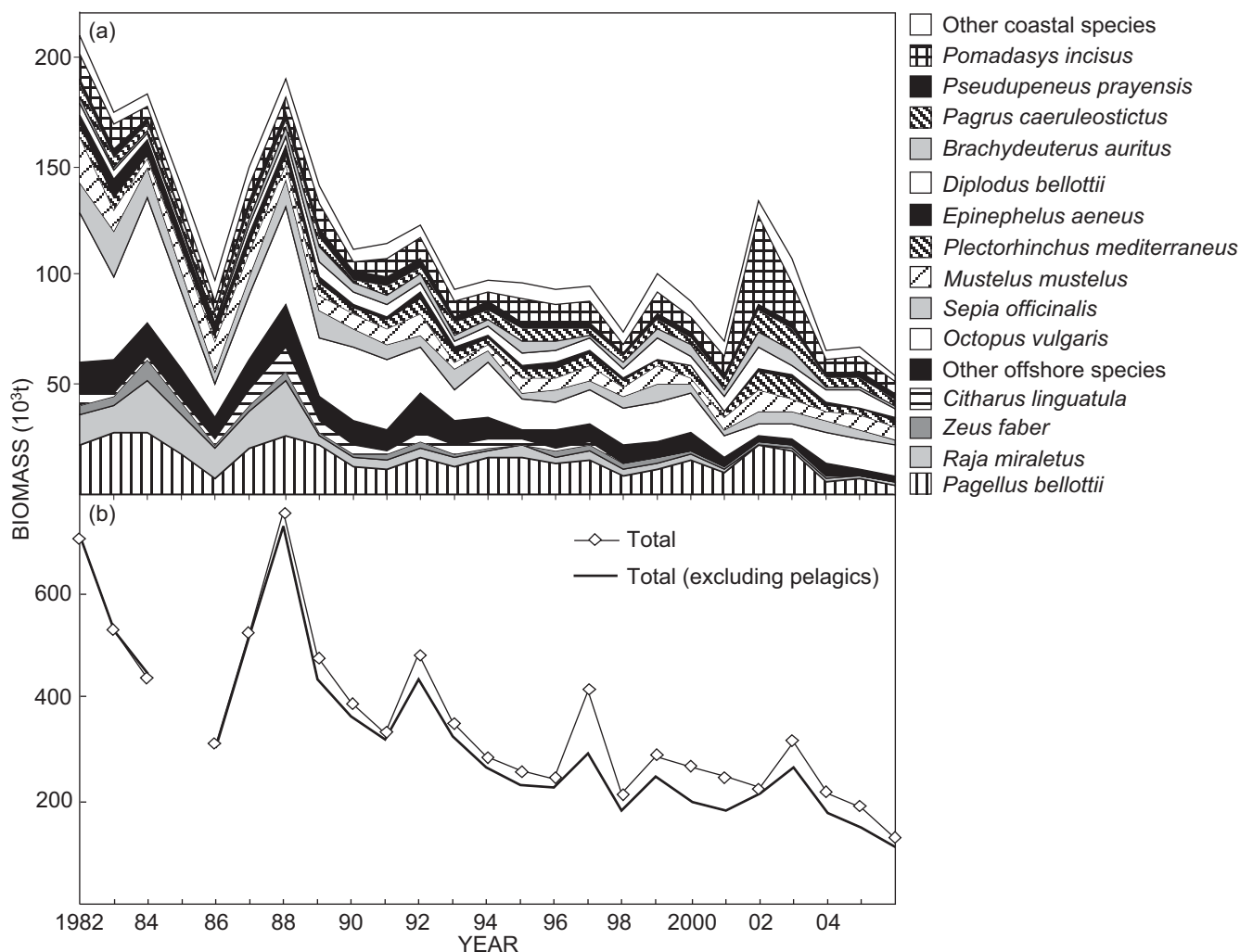


Figure 2: Trend in (a) biomass for the 24 studied taxa and (b) for the total biomass caught by the bottom trawl

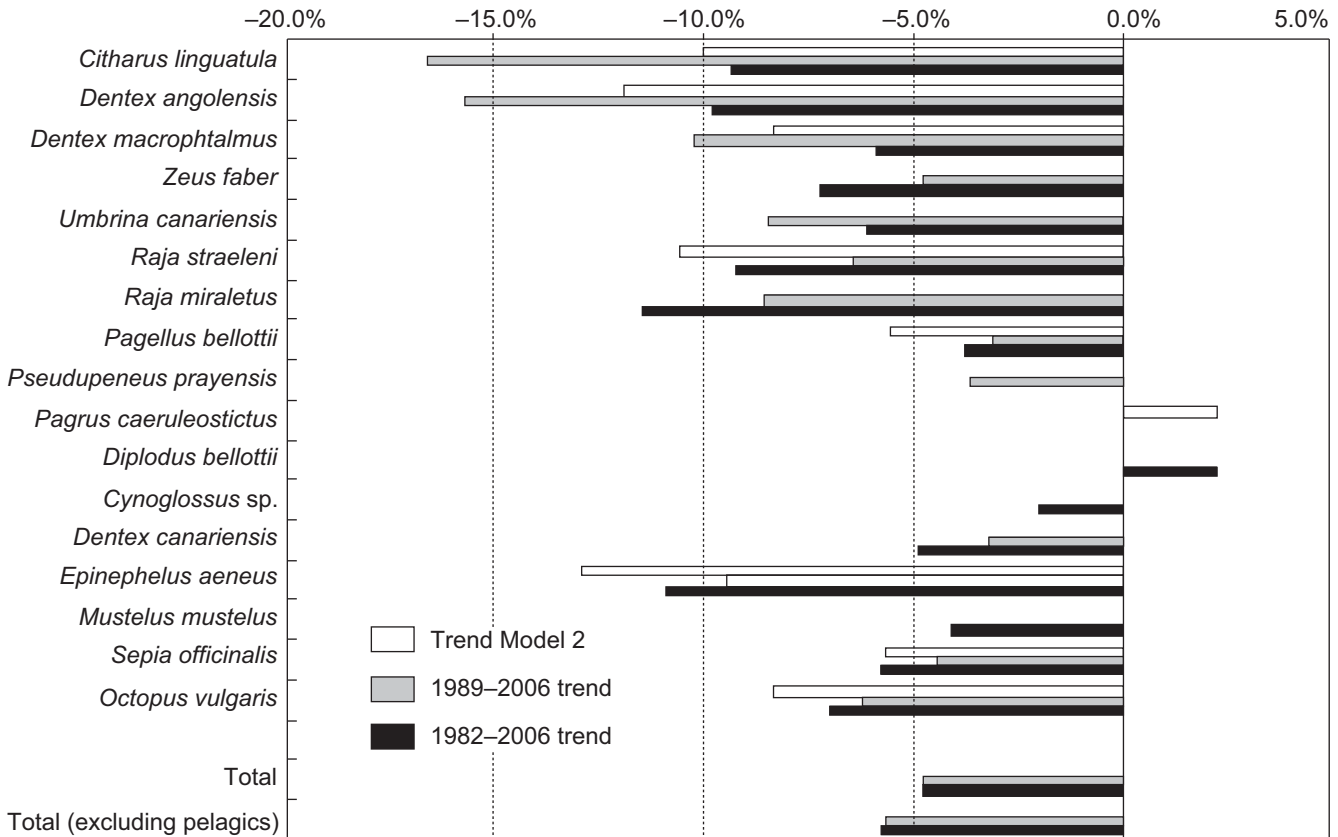


Figure 3: Mean yearly rates of decrease in biomass (rates were calculated from the standard model for the two periods, 1982–2006 and 1989–2006, and from the model with interaction (Model 2); only those with significant trends are shown)

vulgaris, from 20 000t to 5 000t for *Sepia officinalis* and from almost 30 000t to just below 8 000t for *P. bellottii*. Biomass ratios between the earliest and the most recent years indicate a decrease of roughly 10-fold for five species (*Raja miraletus*, *Raja straeleni*, *D. macrophthalmus*, *Umbrina canariensis* and *Zeus faber*) and a 20-fold decrease for three species (*E. aeneus*, *D. angolensis* and *C. linguatula*). The decrease appears to be greater for the offshore species, whose cumulated biomass decreased on average 7.0% per year compared with 3.1% for coastal taxa.

A similar trend was found for the period 1989–2006. For some species, however, the annual rate of biomass decrease appears higher in the recent period (e.g. both species of *Dentex*). Conversely, other species such as *Raja* and *E. aeneus* seem to have declined more slowly during recent years.

Generally, linear models that include the interaction terms for depth and period yielded biomass estimates that are extremely variable from year to year, and are rather unrealistic. For example, some long-lived species show abrupt changes in biomass that are not justifiable by their stock dynamics. For instance, the very high estimate of *E. aeneus* biomass in 1984 (Figure 4a) was on account of a small number of coastal hauls with exceptionally high catches of that species. This example shows that such models are often too sensitive to local or seasonal change in the biomass distribution or catchability. Nevertheless, the long-term trend of decreasing biomass is clearly shown in this study.

For the six species that showed a significant trend in abundance and a significant change in their depth distribution, models including the interaction factors indicated a slightly higher decrease in biomass (see Figure 3), except for *Mustelus mustelus*. For this coastal species, the standard model showed a decreasing trend. Conversely, the model with interaction indicates a strong biomass decrease for *M. mustelus*, but only in the deepest strata, with no significant trends linked to high variability for other strata and for the whole stock (Figure 4b). Therefore, there may have been a contraction in the distribution of this species, the decrease in abundance mainly occurring in areas of low densities and in marginal habitats. Conversely, for *P. bellottii*, the yearly rates of decrease were higher for the coastal strata where it is more abundant (Figure 4c). In other cases, there was no difference in trends by depth class or any clear relation between abundance and rate of decrease (Figure 5a). The rate of decrease, however, seemed to be higher when calculated by depth strata compared with the standard model estimate.

Four species exhibited a significant change in their latitudinal distribution (Figure 5b). For *O. vulgaris*, this was on account of that species having two distinct stocks. The northern stock is the more abundant and subject to the higher exploitation rate than the southern stock; it showed the stronger rate of decrease over the study period. For *S. officinalis*, *R. straeleni* and *A. regius*, which are generally

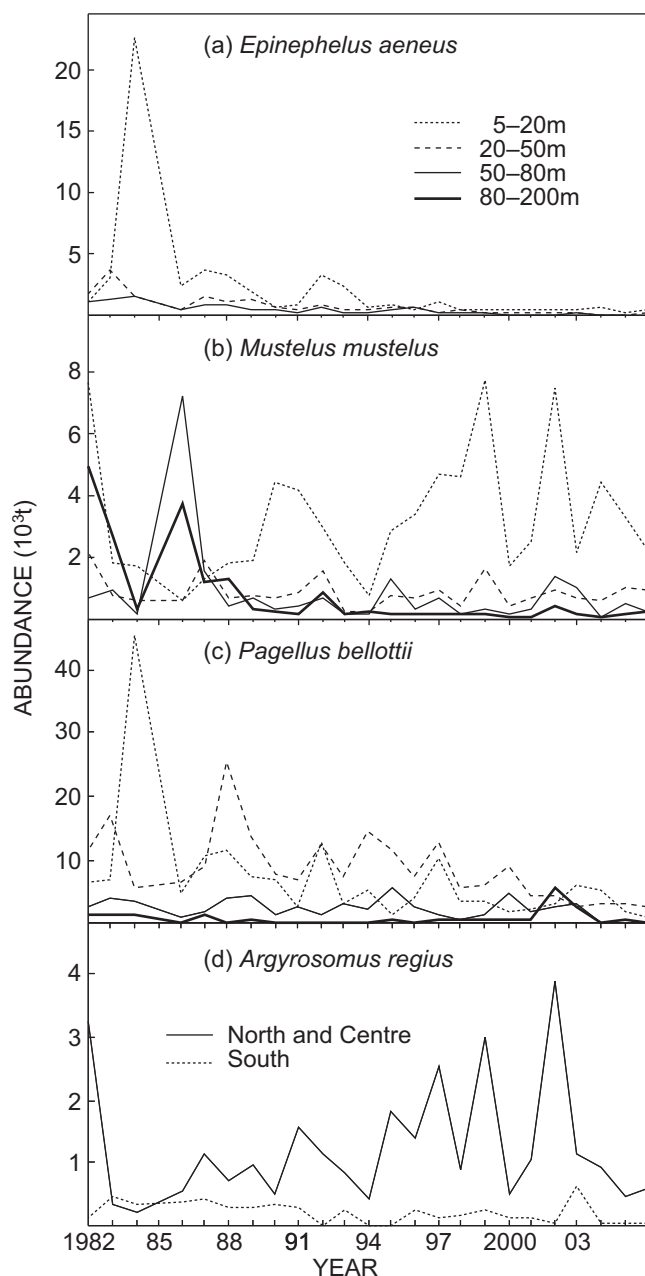


Figure 4: Annual variation in abundance per strata for four species on the Mauritanian shelf, for the period 1982–2006

considered as single stocks, a greater decrease was found in the southern part of the Mauritanian shelf. The abundance of *A. regius* decreased in the south and significantly increased in the north between 1983 and 2003 (Figure 4d).

Standard models gave more stable results, but they may have underestimated the decrease in abundance, although the difference between both approaches is small overall (Figure 5c). There was no significant interaction for the total demersal biomass, whereas the mean rate of annual decrease varied from 4.1% to 5.0% for the cumulative abundance when changes in the spatial distributions were taken into account.

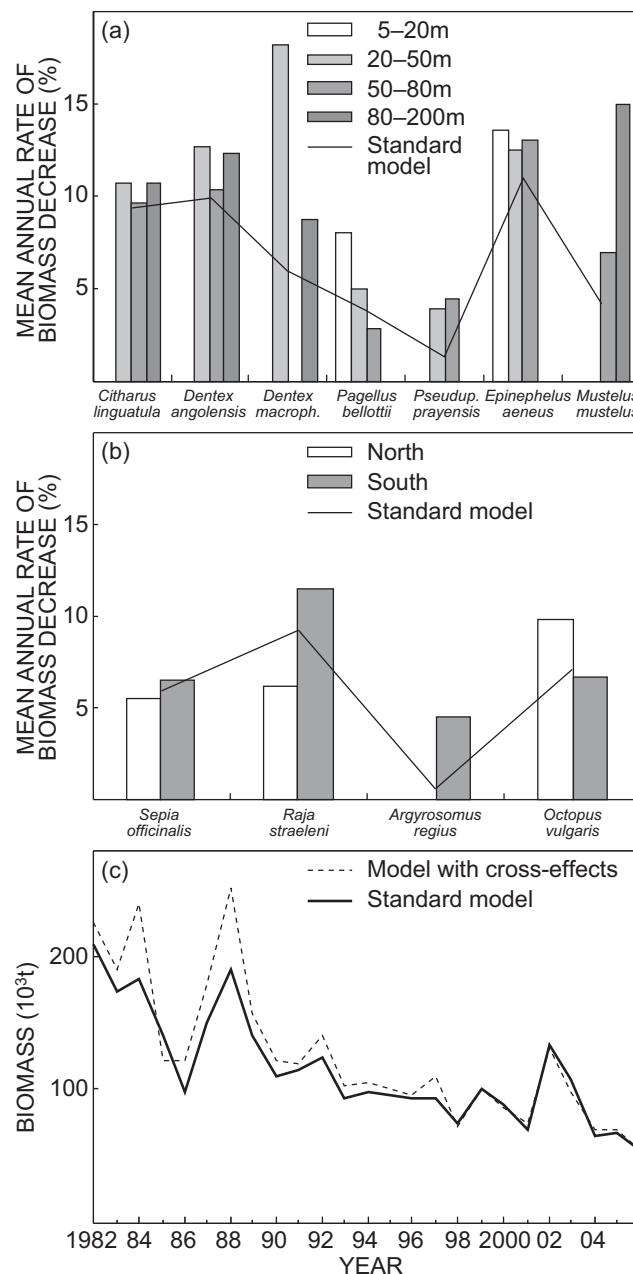


Figure 5: Comparison between the standard model and the model with interaction for (a) mean annual rates of biomass decrease per depth stratum, (b) mean annual rates of biomass decrease per latitudinal area and (c) trends in the cumulative biomass of the 24 studied taxa, with and without interaction. Note that only the species exhibiting a cross-effect between year and strata, and only rates related to significant trends, are shown in (a) and (b)

Biomass Trophic Spectra

BTS, estimated by five-year periods and by depth class, showed a consistent pattern of change in abundance and trophic structure during the 25-year study period (Figure 6). In the offshore zone (depth 50–200m), there was a continuous decrease since the late 1980s (Figure 6a), intensifying during the 1990s and slowing down during the last period.

Qualitative changes add to this overall decline in abundance. At the beginning of the study period, predators in the high trophic levels (around 4) dominated the demersal community. They were the most affected by the decline, with their total biomass having decreased eightfold over a 20-year period. In comparison, the biomass in trophic level 3.3 was reduced by about half, which may explain their dominance in recent years.

In the coastal zone (5–50m), biomasses were higher and the trophic structure was dominated by intermediate trophic

levels, at around 3.5 (Figure 6b). The shape of the biomass decrease inshore differs from that found offshore. A first phase of reduction occurred during the early 1990s, affecting all trophic levels, but more so the higher levels (around 4) whose abundance was reduced by about one-half. This period of decline was followed by a relatively stable phase during the late 1990s, before a second reduction occurred during recent years. During this last period, species of intermediate trophic levels showed the greatest decrease. Also, there was a biomass increase for the lower trophic levels (near 2) during that period, mainly on account of an associated increase in the abundance of the gastropod *Cymbium cymbium*.

The BTS of both zones showed a global decline in biomass of the Mauritanian demersal fish resources, which affected all trophic levels but mainly the higher levels (Figure 6c). The mean trophic level of the catchable biomass clearly decreased from just over 3.7 at the beginning of the study period to below 3.5 at the end (Figure 7), corresponding to an annual decline in the mean trophic level of 0.012.

Discussion

Estimating trends in marine resources abundance

Estimating the abundance of the marine living resources remains a complex issue. Estimates are usually based either on commercial fisheries data or on scientific survey. Commercial data are often very numerous and provide a good geographical coverage; however, estimates using such data can be very biased, particularly as a result of changes in fishing strategy and increases in fishing efficiency. This bias is one of the major sources of controversy in works that have reported on the fast degradation of fisheries resources (e.g. Caddy *et al.* 1998, Ben Yami 2003, Hampton *et al.* 2005). Conversely, abundance estimates that are based on scientific fishing surveys are generally considered more reliable because the standard protocol sampling and the fishing efficiency is theoretically consistent

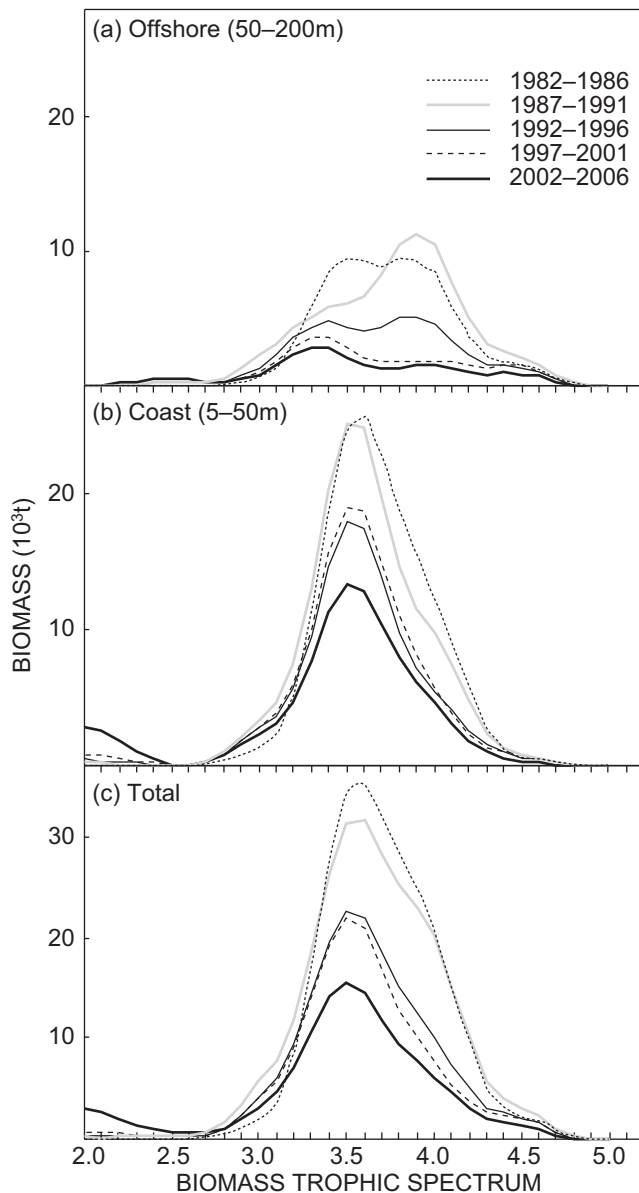


Figure 6: Biomass Trophic Spectrum (BTS) by five-year period in (a) the offshore zone, (b) the coastal zone and (c) the whole Mauritanian continental shelf. Each BTS represents the distribution of the biomass according to its trophic level. Note that the BTS of the first period (1982–1986) is atypical and is in fact a biased shape, due to the use of the categories 'others' during the first three years of sampling

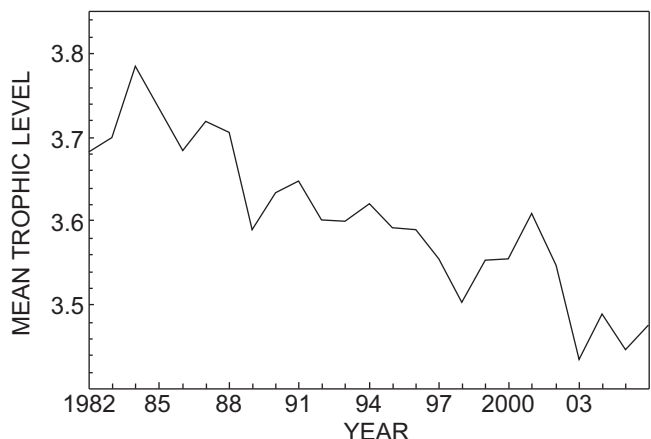


Figure 7: Variation of the mean trophic level of the demersal catchable biomass in Mauritania for the period 1982–2006

from year to year. Even in the case of changes of ship or gear, as was the case for the present study, when the trawl was replaced in 1989, changes in abundance can be identified and theoretically fishing power can be standardised using calibration methods (Pelletier 1998). In such cases, due to the small size of sampling units, standardisation coefficients were calculated per species category. In spite of the uncertainty introduced by this procedure, declining trends in biomass and trophic levels were consistent across all periods and gear considered.

A major limitation in using data from experimental surveys is the limited geographic coverage and small number of samples relative to commercial samples. The present study is no exception as each trawling survey had a limited number of hauls (between 51 and 114) and it covered a total trawled area of about 5 km², which is <0.02% of the Mauritanian continental shelf. In addition, fish generally have a heterogeneous distribution, both in time and space, while sampling effort is limited and corresponds to specific hydro-climatic conditions and thus of fish vulnerability. As a consequence, abundance between hauls varies considerably and can lead to large variances in estimates. Therefore, the use of aggregated data is strongly recommended. Such a procedure limits the proportion of zero values and thus normalises the distribution of the studied variable. It also helps to smooth the local small-stock variability due to habitat characteristics, in particular. This variability may be analysed in specific studies, using binomial models and using these habitat characteristics as dependent variables. However, in the present study which aims to estimate global trends, it is considered as random noise that cannot be explained. Long-term studies have to deal to large-scale observations, and aggregated data have to be considered.

In order to obtain reliable estimates, linear statistical models need to be considered (Robson 1966, Sissenwine and Bowman 1978). Such methods allow the statistical testing of the various factors included in the model, such as the year-to-year variability of fish abundance, and the use of all the information contained in a dataset. Essentially, rather than taking each survey into account separately, a seasonal distribution pattern can be averaged over the whole sampling period. Variability in space and seasonal distribution is thus included in the error term and is considered as non-interpretable. Conversely, the index of abundance is estimated as the common year-to-year variability that is observed in the various strata (depth, latitude, season). This leads to more robust indices, but the trends can be skewed by changes in spatial distribution (Laurec 1977).

It is generally recognised that the distribution area of a stock decreases as its abundance decreases, as illustrated by the 'basin model' theory (MacCall 1990). Thus, it would be expected that reductions in the stock would take place mainly at its periphery. In the present study, such an effect was found only for *M. mustelus*. For other taxa, no significant differences between strata were observed. This may be on account of high sampling variability or the behaviour of fishers, who do not target the margins of the distribution but rather zones of high abundance. Therefore, marked decreases in biomass observed in strata of high abundances seem to confirm the role of fishing. For *Pagellus bellottii*, a species

of high commercial interest, the decrease is even stronger in the centre of its distribution, namely the coastal zone.

Theoretically, models with interaction allow us to take into account changes in spatial distribution. In practice, however, they appear very unstable and not very reliable for the prediction of annual values, because of the strong sampling variability. In spite of this, the resulting trends are remarkably consistent across models. They confirm that standard models slightly underestimate the average rates of reduction in biomass.

Another difficulty regarding analysis of survey data is the transition from an index of abundance (proportional to the observed density) to an estimate of absolute biomass. Our estimate is based on empirical coefficients assuming that the catchability of octopus (which hide in crevices) and cuttlefish is weaker ($q = 0.2$) than for most of other studied fish ($q = 0.5$). These values are applicable to the trawl used since 1989; they remain largely arbitrary and merely attempt to scale relative abundances to reasonable order of magnitudes. We also included in the northern coastal stratum the area of Banc d'Arguin, where few hauls were made. The unique oceanographic and ecological characteristics of this area may have induced a bias in the estimates. Nevertheless, they are presently the only available estimates and we chose to extrapolate results to the entire Mauritanian continental shelf.

Our absolute biomass estimates are markedly higher than those previously published for similar stocks. Indeed, using a catchability coefficient of 0.5, the biomass of demersal fish was estimated to be 170 000t for the period 1982–1984 (Josse and Garcia 1986). However, this coefficient corresponds to the former trawling gear used prior to 1989, and it is likely an underestimate. Conversely, if we assume that the value of 0.5 is correct for the new trawling gear, the standardisation coefficients from Table 1 suggest that Josse and Garcia's (1986) estimate should be more than doubled. Thus, in the present study the biomass of demersal fish is estimated to be between 300 000t and 400 000t for the period 1982–1984, and around 100 000t in recent years. These latter estimates are more consistent with the reported commercial catches, estimated at 60 000t in 1996–1998 (Gascuel *et al.* in press a), and excluding bycatch and unreported catches. In the case of cephalopods, estimated catches are of the same order of magnitude as the estimated biomass, which varied between 80 000t and 30 000t during the study period. Although the absolute biomass may still be underestimated, the trends, however, are considered reliable.

Declines owing to fisheries

The period 1982–2005 covered by scientific surveys coincides with considerable development of demersal fishing in Mauritania (Figure 8). During the first 15 years of this period, the number of industrial fishing vessels increased from approximately 150 vessels to more than 300 and fluctuated between 300 and 350 over the past 10 years. In parallel, the number of fishing days increased from fewer than 40 000 days per year in 1991 to more than 60 000 days in 1996 (Brahim *et al.* in press). Assuming a probable

increase in fishing efficiency due to technological development, the industrial fishing pressure on demersal resources more than doubled over the study period, and stabilised somewhat in recent years.

Simultaneously, small-scale fisheries showed extraordinary development. The number of pirogues, close to 500 in 1982, reached approximately 800 in 1992 and then increased dramatically to 2 000 pirogues in 1995 and to almost 4 000 in 2005 (IMROP 2007). An increase in the size of these vessels, the development of motorisation and improvement of navigation instrumentation led to a major increase in fishing power (Chavance 2004). Thus, the effective fishing effort of this fleet was probably increased by a factor of 10 during the past 25 years. From its historically marginal position, the small-scale sector became very important in Mauritania, with landings exceeding those of the industrial sector (Chavance *et al.* 2006).

Undoubtedly, the sizeable increase in fishing pressure is the main cause of the reduction in abundance of demersal resources in Mauritania. A very characteristic scheme of development is apparent, with successive underexploitation, then full exploitation and finally overexploitation that affected one species after the other. For example, the exploitation of *Octopus vulgaris* by industrial trawlers (mainly foreign fleets) developed in the 1960s, and at the beginning of the 1980s the stock had reached the level of fully exploited. Since then, various stock assessments have confirmed that the stock is overexploited (Gilly and Maucorps 1987, Ould Mahmoud *et al.* 2006, Chassot *et al.* in press). Thus, total landings of cephalopods reached a maximum of approximately 55 000t in 1986 and 1987 and then decreased to 35 000t in 2005.

In the absence of fisheries data by taxon, there is no stock assessment for any demersal fish, but the analysis of the commercial catches gives a similar scenario to that of the octopus (Table 4). In the 1980s, changes in the structure and strategies of the industrial fishing fleet probably caused the observed fluctuations in landings of between 20 000t and 45 000t (FAO-CNROP 1995). Subsequently, landings increased due to the development of the small-scale fishery and also to a renewed interest by industrial fleets. Landings peaked at approx. 60 000t in 1996–1998, and corresponded to the maximum sustainable yield (Gascuel *et al.* in press a). The decline in biomass leading to a decrease in catches (approx. 40 000t in 2005), in spite of an increase in fishing effort, indicates that demersal species are overexploited. Moreover, the mean trophic level of the demersal fish landings may be calculated based on catch statistics per taxa (from IMROP database, cited in Gascuel *et al.* in press a). The trophic level of the landings decreased from 3.65 to 3.25 between 1997–1998 and 2004–2005, a very marked decrease in such a short period, and confirms the rapid degradation of the demersal resources status.

The interaction between small-scale and industrial fleets is also an important aspect to consider. As long as the small-scale fleet was undeveloped, increasing industrial fishing effort resulted in an increase in landings of cephalopods and demersal fish (from 60 000t to 80 000t between 1982 and 1986). However, in the past 15 years, these industrial landings have declined appreciably and have remained at about 45 000t, in spite of increasing fishing effort. During that period, the decline in cephalopod

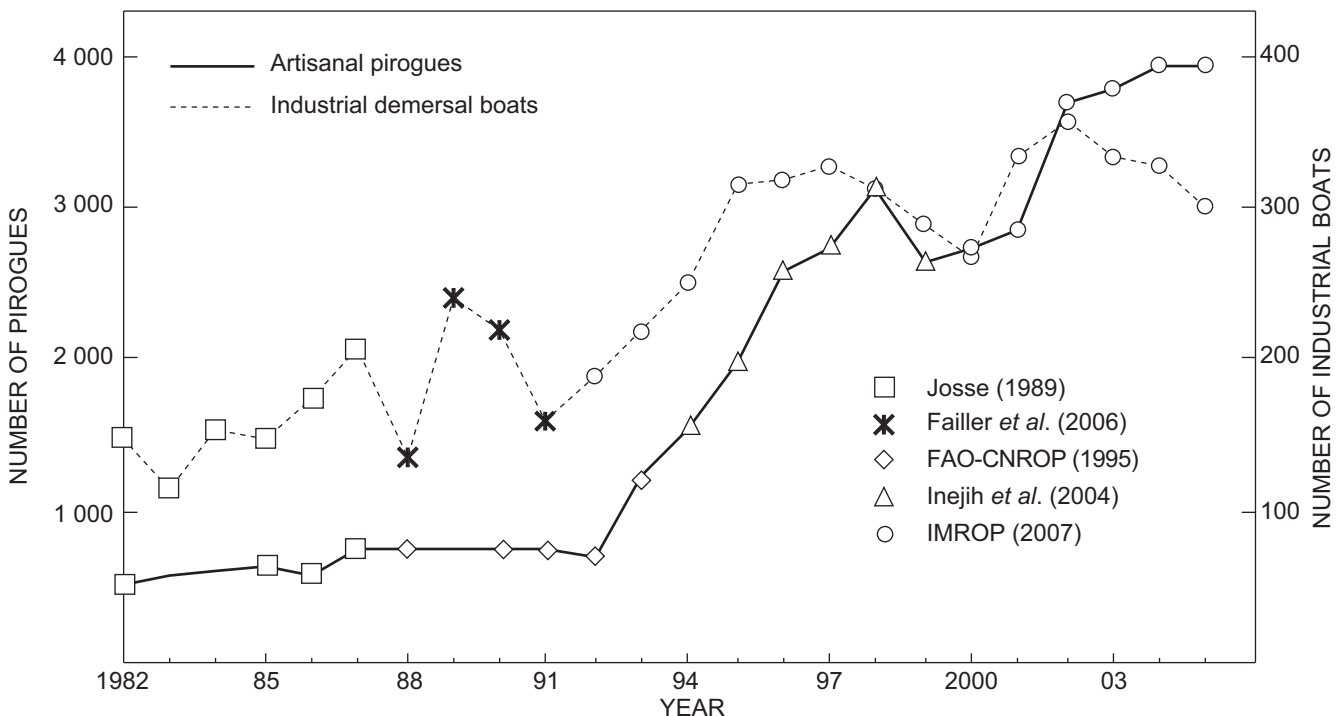


Figure 8: Number of vessels in the small-scale and the industrial demersal fisheries of Mauritania for the period 1982–2005, based on data from various sources

catches was initially compensated for by catches of demersal fish, which in turn declined and were replaced by shrimp catches and species of the continental slope (e.g. hake). In contrast, due to the very large increase in the fishing effort, landings from the small-scale sector steadily increased until 2000. Since then, in spite of the recent increase in number of pirogues from 3 000 to 4 000, landings have stabilised, the decline in landings of demersal resources (cephalopod and fish of the continental shelf) being compensated for by an increase in catches of sardinella and mullet.

Trends differ between areas. Over the past 15 years, three successive phases were observed: (1) firstly, there was an increase in the fishing effort in both the coastal and the offshore areas, mainly on account of the industrial fleet in the early 1990s; (2) subsequently, a concentration of the fishing effort in the offshore area, probably in response to the decrease in octopus biomass; (3) and finally, a concentration in the coastal zone precipitated by very low offshore biomasses and targeting of mainly demersal fishes.

Environmental effects?

Mauritania has not escaped the effects of climate change and the most recent working group organised by the Institut Mauritanien de Recherches Océanographiques et des Pêches showed a significant rise in temperature since 1970, correlated with a reduction in upwelling intensity (IMROP 2007). It could be expected that this change might cause the distribution of some species to shift northwards, and it may explain the changes in latitudinal distribution observed for *A. regius*, *S. officinalis* and *R. straeleni*. More generally, this could have long-term effects on the catch composition and on the underlying biomasses.

It is improbable, however, that climatic changes played a major part in the overall decline in abundances in the study region, as the increase in fishing effort is sufficient in itself to explain the trends described earlier. Moreover, temperature and upwelling indices remained stable from 1982 to 1994, but changed in subsequent years (Figure 9), and thus cannot explain the decreasing trend in biomasses observed in the 1980s. More importantly, the trophic spectrum analysis shows that the decline in biomass of high trophic-level predators was three times larger than the decline in biomass of species at lower trophic levels. There is no indication that the

high trophic-level predators are generally more sensitive to climatic changes, but they are likely to be more severely affected by fishing, for at least three reasons: (1) these species are generally long-lived and grow slowly and are more vulnerable to fishing pressure, mainly because of longer regeneration times (Gascuel 2005); (2) these species are often targeted because of their high commercial value, and thus are subjected to higher fishing pressure; and (3) the reduction in prey abundance, also subjected to high fishing mortality, adds to the direct impact of fishing.

Whereas climatic changes probably had little impact on the observed biomass trends, the interannual climatic variability seems to play a significant role in year-to-year changes in abundance. For instance, there seemed to be a good correlation between high yields of octopus and strong upwelling in the period 1968–1982 (Sy Moussa and Tchernichkov 1985), although these results are controversial (Josse and Garcia 1986). Other studies have also suggested that strong upwelling could have a positive effect on the recruitment of octopus (Faure *et al.* 2000) and perhaps of many other fish (Laurans *et al.* 2002, Laurans 2005). Present results show a significant correlation between the total demersal abundance index of a given year and the upwelling strength of the previous year over the period 1990–2006 ($r^2 = 0.60$, $p < 0.001$), but no correlation was found for early years. Increasing fishing pressure not only induces a reduction in stock abundance but also leads to a truncated age-structure for each exploited population. Therefore, these populations become more dependent on recruitment, which in turn is sensitive to environmental conditions. Thus, two mechanisms seem to be at play, the increase in abundance of the short-lived species (shellfish and molluscs), and the reduction in age structure of most exploited species, due to increasingly high exploitation rates. Hence, the stocks are comprised mainly of young individuals and would become more unstable and more dependent on the recruitment processes.

The general trend in North-West Africa

Based on survey data, demersal resources also show strong reductions in abundance in Senegal and in Guinea (Gascuel *et al.* 2004; Figure 10). In Senegal, the analysis of five stocks indicates a fourfold decline in abundance between 1983 and

Table 4: Mean yearly catches by period in the Mauritanian EEZ for demersal fish of the continental shelf (hake and mullet not included) and for cephalopods

Group	Fisheries	Catch (10 ³ t)				
		1982/83 ¹	1986/87 ²	1991/92 ^{2,3}	1997/98 ³	2004/05 ³
Demersal fish	Artisanal	10.4	9.6	5.5	34.8	24.7
	Industrial	34.2	24.5	15.6	25.2	17.7
	Total	44.5	34.0	21.0	60.1	42.4
Cephalopods	Artisanal	0.0	1.8	6.4	12.6	6.0
	Industrial	25.2	53.3	38.4	21.5	28.6
	Total	25.2	55.1	44.8	34.1	34.6

1 Josse and Garcia (1986)

2 FAO-CNROP (1995)

3 IMROP database (in Gascuel *et al.* in press a)

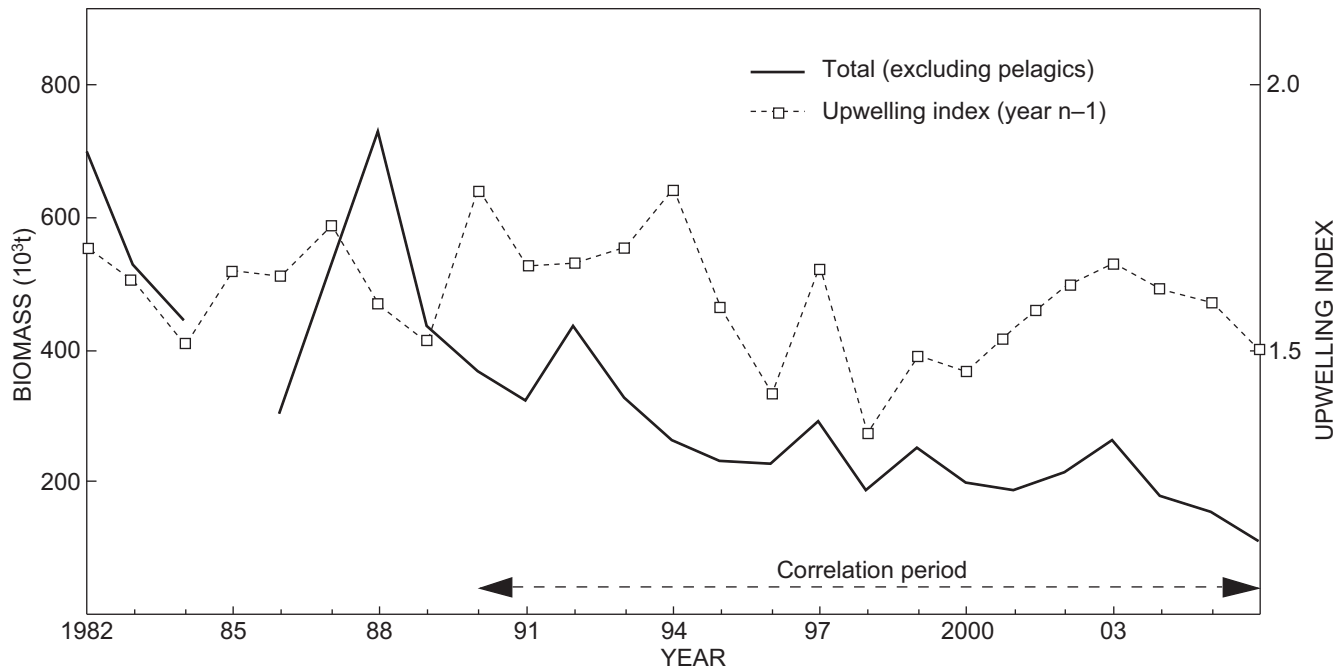


Figure 9: Total catchable biomass of demersal species and annual index of the upwelling strength on the Mauritanian coast (from IMROP 2007) for the period 1982–2006

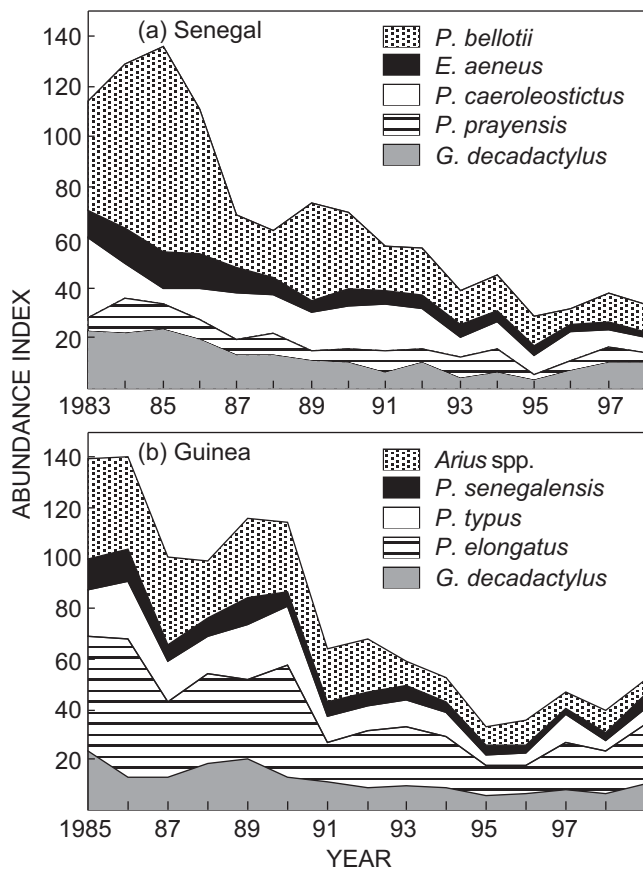


Figure 10: Variation in the abundance indices for selected demersal species in (a) Senegal and (b) Guinea (from Gascuel *et al.* 2004)

1998. In Guinea, a threefold decrease has been observed between 1985 and 1999 for important commercial species and for entire ecological communities dominated by sparids and sciaenids. In both countries, stock assessments have confirmed that most species considered are overexploited (Barry *et al.* 2004, Sidibé *et al.* 2004). As in Mauritania, over-exploitation is more notable and severe for high trophic-level predators, and the decline in abundance is accompanied by a change in the trophic structure of the fish community (Laurans *et al.* 2004a, 2004b).

In these three countries, the reduction in biomass has been documented only since the beginning of the scientific surveys in the early 1980s, although fishing was already important at that time. This is notably the case in Mauritania where the small-scale fleet did not develop until the early 1990s, but the industrial fleets were already landing almost 100 000t per year in the 1970s (Gascuel *et al.* 2007). Josse and Garcia (1986) noted that the 'sparid ecological community' of the continental shelf has consistently been targeted by international fleets, undoubtedly as early as the 1950s and 1960s when sparids dominated the shelf community. However, those authors noted that by the mid-1980s the shelf community was dominated by cephalopods following extremely severe overexploitation of sparids.

Based on the aforementioned, the following sequence of events would have likely occurred in Mauritanian waters. Sparids were exploited intensively, starting in the 1960s, and they dominated the catches until the mid-1970s. The reduction in their abundance would, to some extent, be responsible for the increase in octopus abundance in the late 1960s (Bas 1979, Caddy 1981). Cephalopod fisheries then took over and became dominant in the 1980s and

early 1990s. By that time, both the small-scale fleet and a part of the industrial fleet began to intensively exploit the scianids of the more coastal ecological community, to the extent that these fish dominated the landings in the mid-1990s. As this community became overexploited in the 2000s, shrimp abundance increased (Inejih and Corten 2005) and became an additional target as did other species such as small pelagics and mullets.

In Senegal, the development of demersal fisheries occurred earlier and different from that in Mauritania. The small-scale fleet developed in the 1950s and the industrial fleet in the 1970s (Garcia *et al.* 1979). From the beginning, both fleets exploited demersal fish over the entire continental shelf. Landings peaked in the mid-1980s and decreased as the biomasses declined due to very heavy overexploitation. The cephalopod fisheries in Senegal, being much less important than in Mauritania, developed in the late 1980s and showed signs of overexploitation by the mid-1990s (Laurans *et al.* 2002). As in Mauritania, shrimp abundance recently increased, suggesting that the ecosystem is also being modified in Senegal.

In Guinea, deep-water species of the continental shelf were exploited by foreign fishing fleets in the 1970s. More intense exploitation of the coastal communities, particularly the scianids, started in the 1980s, with landings increasing until the end of the 1990s. Overexploitation in Guinea has been less intense than in Mauritania and Senegal; landings started to decline only recently, and the fisheries for cephalopods and shrimps are only now starting to develop.

The progressive reduction of demersal resources thus results in the successive exploitation of various groups. To a certain extent, this demonstrates a capacity of both fisheries and ecosystems themselves to react to overexploitation. However, this is not simple species replacement and the trend is not 'neutral' from an ecological point of view. Indeed, it was shown that this succession of fishing targets was accompanied by a severe reduction in total biomasses; landings were initially maintained by a tremendous increase in fishing effort and thus in total exploitation rates. In addition, we have observed the phenomenon of 'fishing down the marine food web' (Pauly *et al.* 1998). The quasi-disappearance of high trophic-level predatory fish species and the reduction of mean trophic level of fish communities can be interpreted as a loss of biodiversity (Pauly and Watson 2005). This indicates ecosystem degradation which is accompanied by a greater sensitivity to environmental conditions. Finally, the resilience of ecosystems and fisheries does have limits; the reduction in total catches of demersal fish, observed in the various countries, has forced fishers to transfer part of their effort towards pelagic resources or deeper water resources.

More generally, our results highlight some major ecosystem changes. They also raise the possibility of adaptive changes of the demographic strategies within the demersal fish communities, caused directly (by extractions) or indirectly (by habitat destruction), by fishing activities. Such issues will have to be investigated in the future; they seem nevertheless to confirm that heavy exploitation tends to decrease the degree of 'maturity' of the ecosystems.

Conclusion

Until now, fishing has played a major role in the economy of the countries of North-West Africa. This is particularly the case in Mauritania, in which the fisheries sector has high macro-economic importance. Nevertheless, probably because of the pre-eminence of pelagic fisheries, and with the exception of octopus which has increase in abundance, the decline of demersal species has been poorly studied until now. The present study helps to fill this gap in knowledge and reflects the severe degradation of the demersal resources already observed in neighbouring countries. In general, the abundance of the demersal resources of North-West Africa has declined by a factor of 4 over the past 20–30 years. This decline is particularly marked for high trophic-level predatory fish, which have been reduced by a factor of 10, and even 20 for the most affected species. This trend hinders the capacity of the industrial and small-scale demersal fisheries to contribute to development of these countries, and, in the short- or medium-term, it could threaten the fishing fleet's economic viability.

Strong reductions in biomasses caused by fishing are also observed elsewhere in the world. For example, Stobutzki *et al.* (2006) highlighted a severe decline of coastal demersal resources in some Asian countries; a 10-fold reduction occurred within a 30-year period. At a worldwide scale, a 10-fold reduction was observed not only in the abundance of large predators (Myers and Worm 2003) but more generally for many overexploited stocks (Christensen *et al.* 2003).

The Mauritanian study has several advantages: the analysis is based on data from scientific surveys and thus is not biased by possible changes in fishing power; the estimates cover the entire demersal resource over the continental shelf; and the analysis of stock biomass is reinforced by an analysis of trophic spectra for all ecological communities.

Our results clearly support the general view of declining trends of world fishing resources. In many countries, the expansion phase of fisheries was completed a long time ago or was spread over a long period, which makes detection of trends difficult. In Asia, as in North-West Africa, a more recent and accelerated succession of fisheries confirms the severe degradation of fisheries resources, and particularly of demersal resources. Moreover, this study shows how the decline in biomass was accompanied by successive exploitation of various target species or groups of species, a clear sign of the general degradation of demersal resources. This study supports calls from the scientific community, in particular in West Africa (e.g. Chavance *et al.* 2004), for urgent and strict regulation with regard to fisheries management.

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